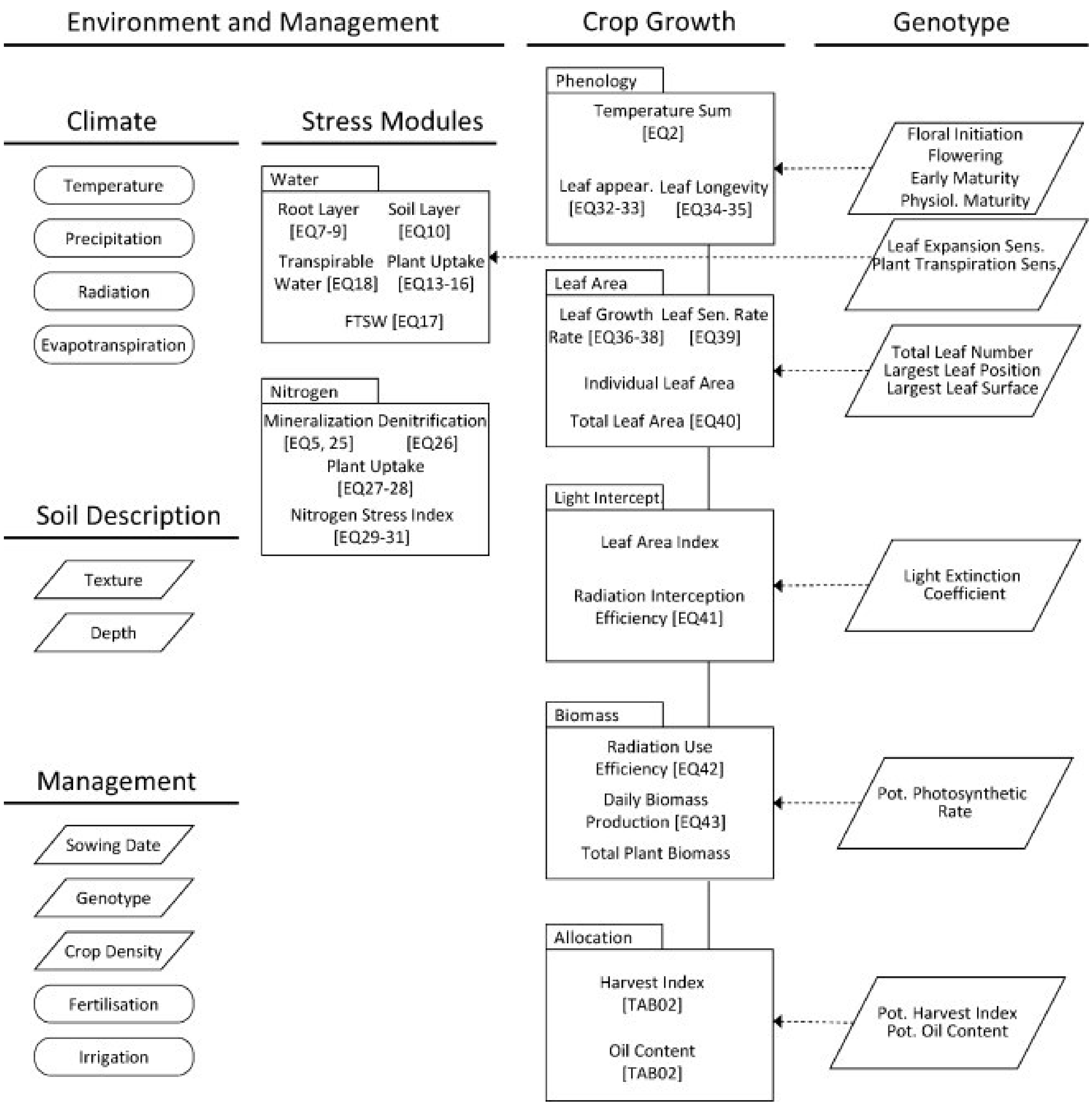
Coupling Remote Sensing and a Sunflower Crop Model

Ronan Trépos (INRA, Toulouse), A. Al Bitar, T. Wijmer, J.-F. Dejoux (CESBIO, Toulouse), S. Buis, M. Gueriff (INRA, Avignon), L. Champolivier (Terres Inovia, Toulouse), P. Casadebaig, P. Debaeke (INRA Avignon), ...

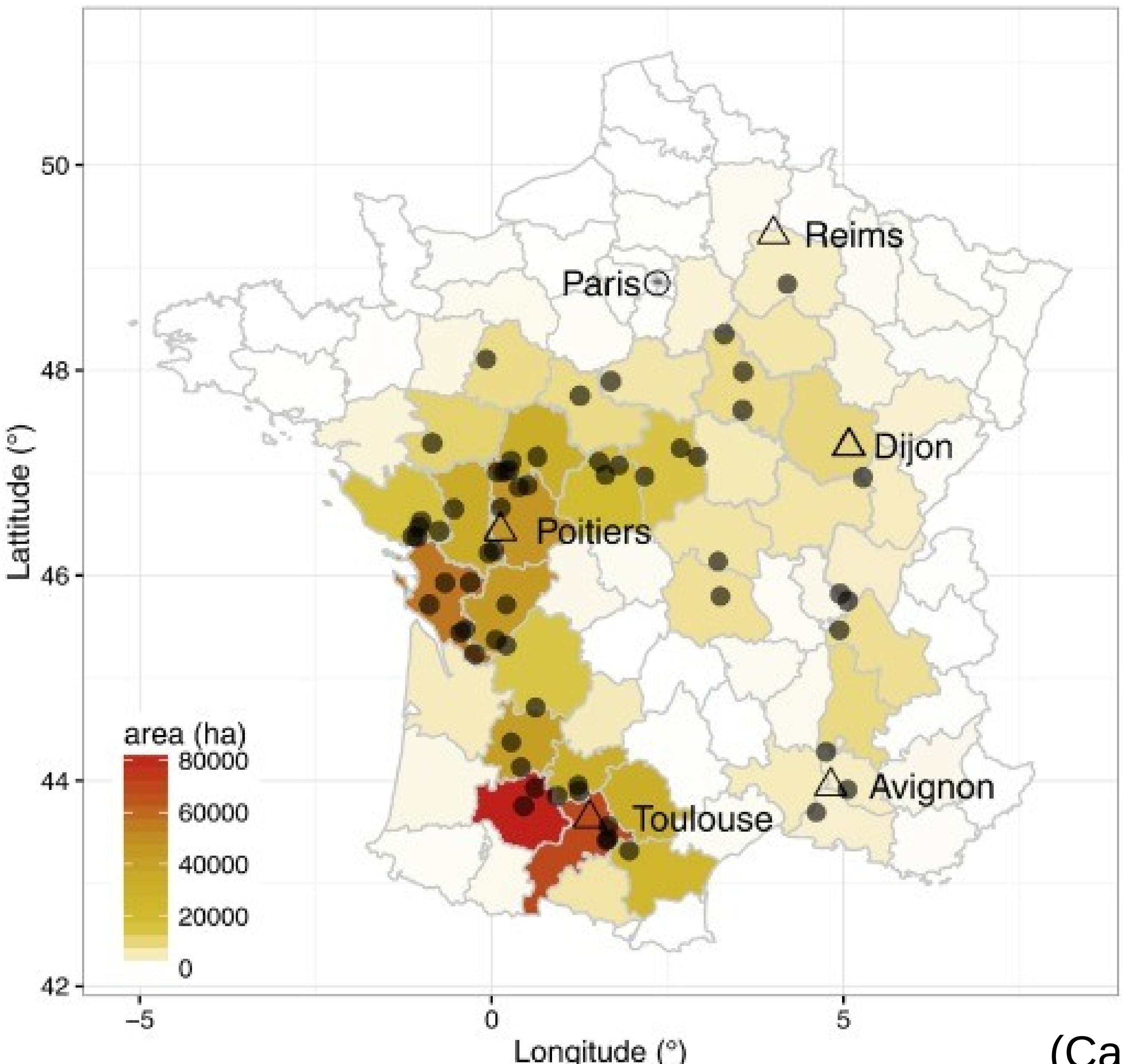
Outline

- <u>SUNFLO: a process based crop model for sunflower</u>
- Sensitivity analyses: importance of soil conditions
- Estimate soil properties by coupling SUNFLO with remote sensing (RUEdesSOLS project)
- Build a forecasting tool for yield by coupling SUNFLO with remote sensing (Casdar project)



SUNFLO: simulated processes and inputs (Casadebaig et al. 2011)

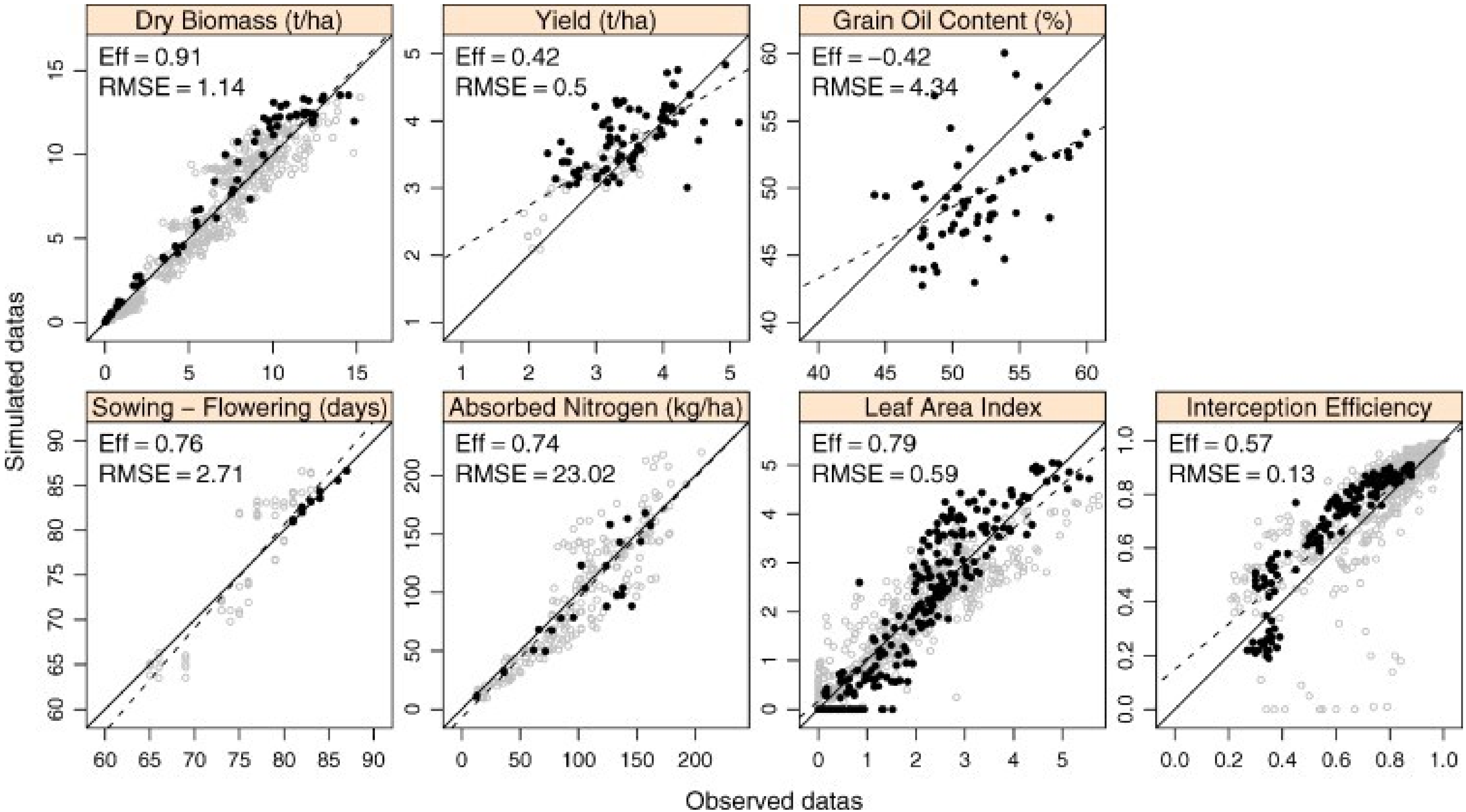
SUNFLO validation



Mapping experimental platforms used for the validation and production of sunflower in France

(Casadebaig et al. 2016)

SUNFLO validation



(Casadebaig et al. 2011)

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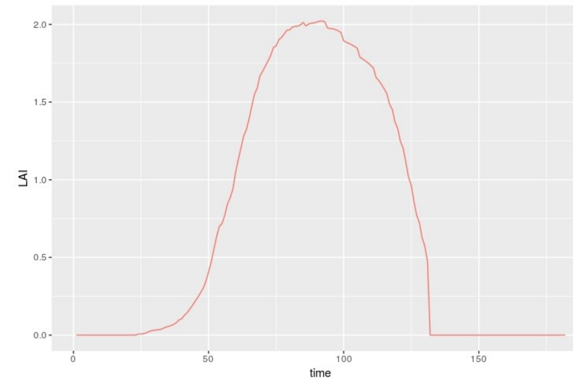
Why sensitivity analysis ?

Input type	**level of uncertainty**
Climate	low (if current climate conditions)
Soil conditions	rather high
Management	can be low at a local scale and high at large scale
Cultivar	rather high

SUNFLO

Yield (t/ha)

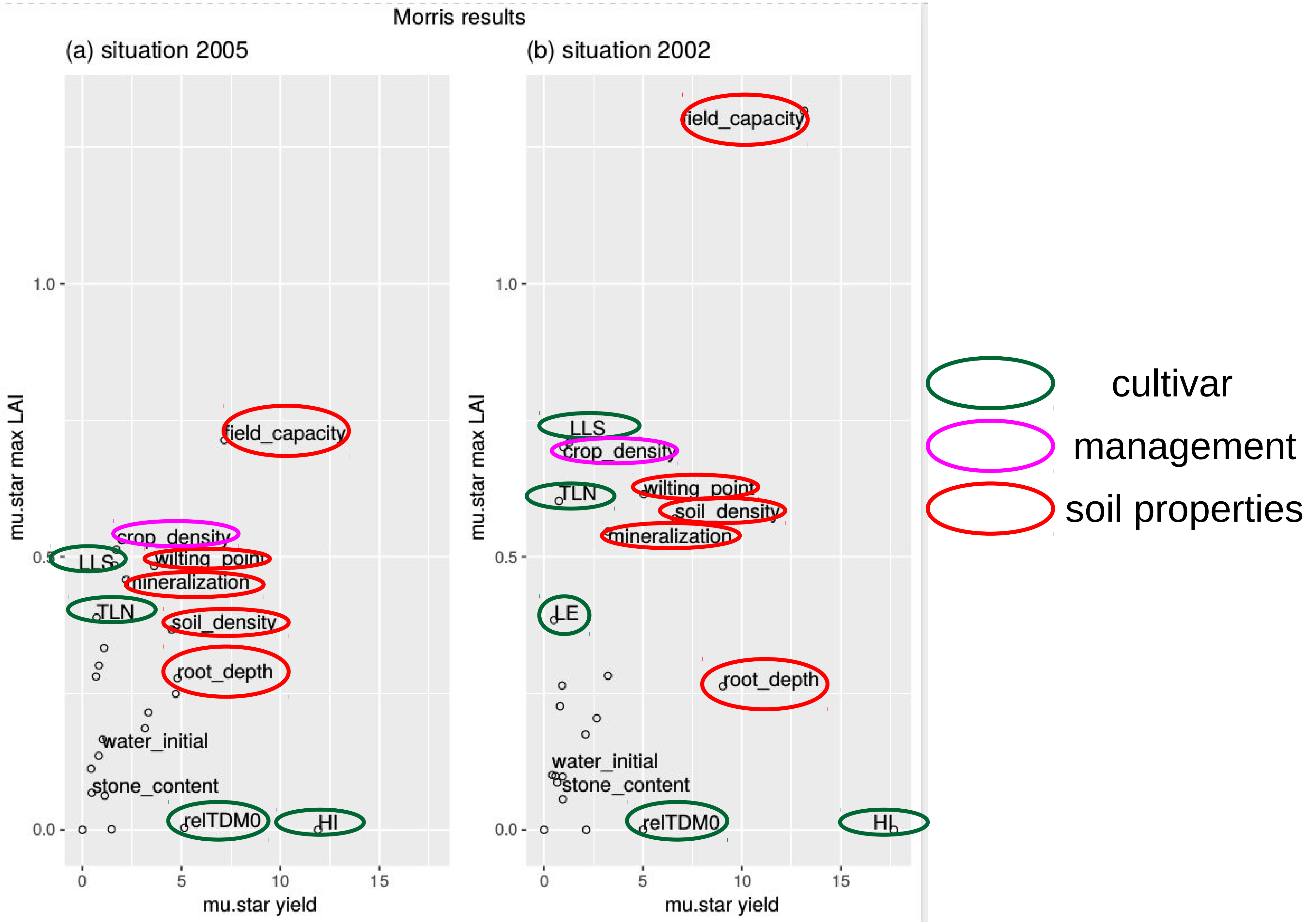
LAI (m^2/m^2)



Does a little difference in soil conditions lead to a high difference in LAI and Yield (and how much in comparison with other inputs) ?

=> sensitivity analyses methods : Morris, Sobol, Fast

Be careful of inputs correlation and non linearity of the model.

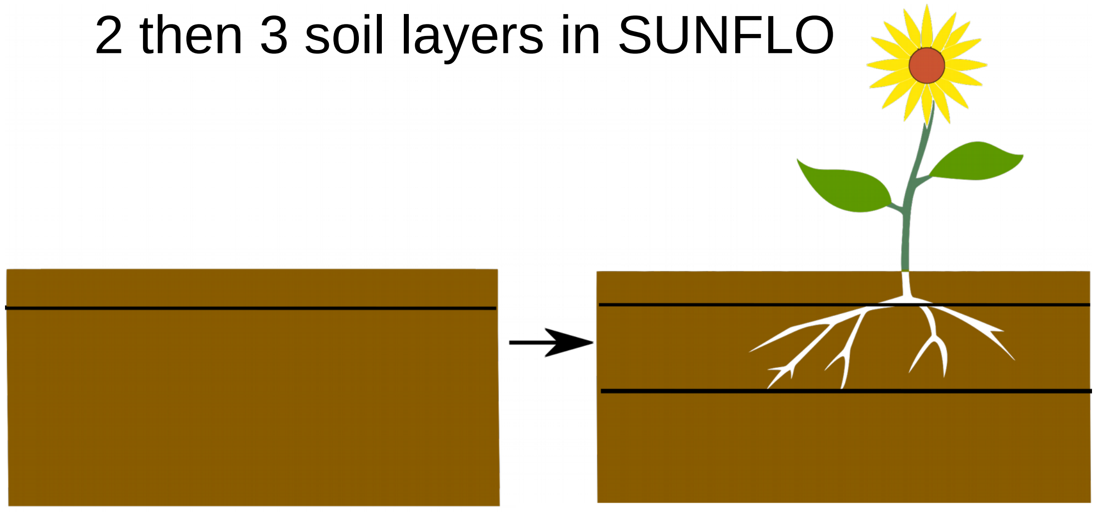


Morris sensitivity analysis of SUNFLO on two contrasted situations
(Trépos et al. in progress)

Available Water Content

- maximum quantity of water available for plant growth
- AWC = (Fc- Wp) * Bd * (1-Sc) * D
- Fc : field capacity
- Wp : wilting point
- Bd : bulk density
- Sc : stone content
- D: soil depth

2 then 3 soil layers in SUNFLO



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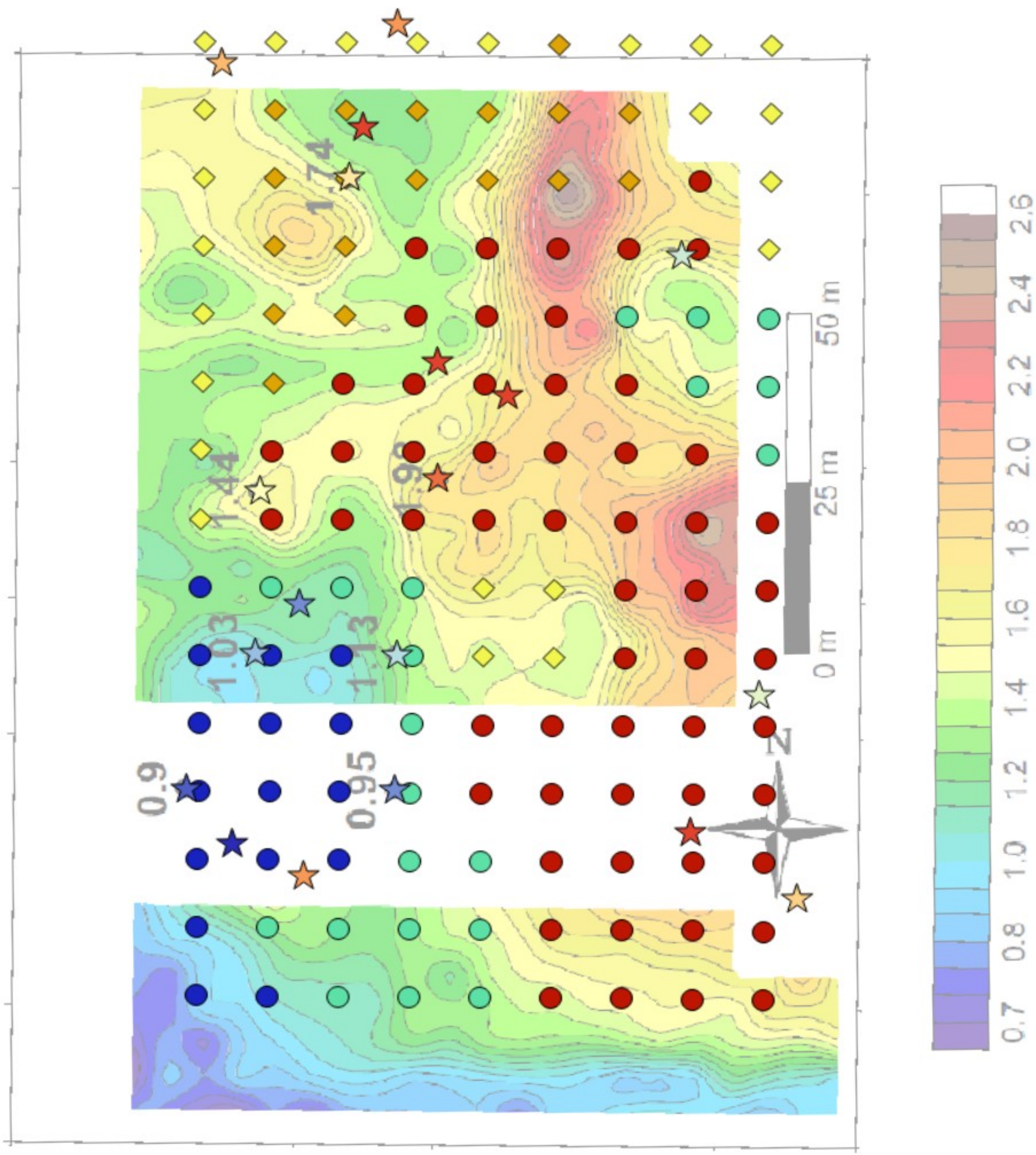
RUEdesSOLS Project

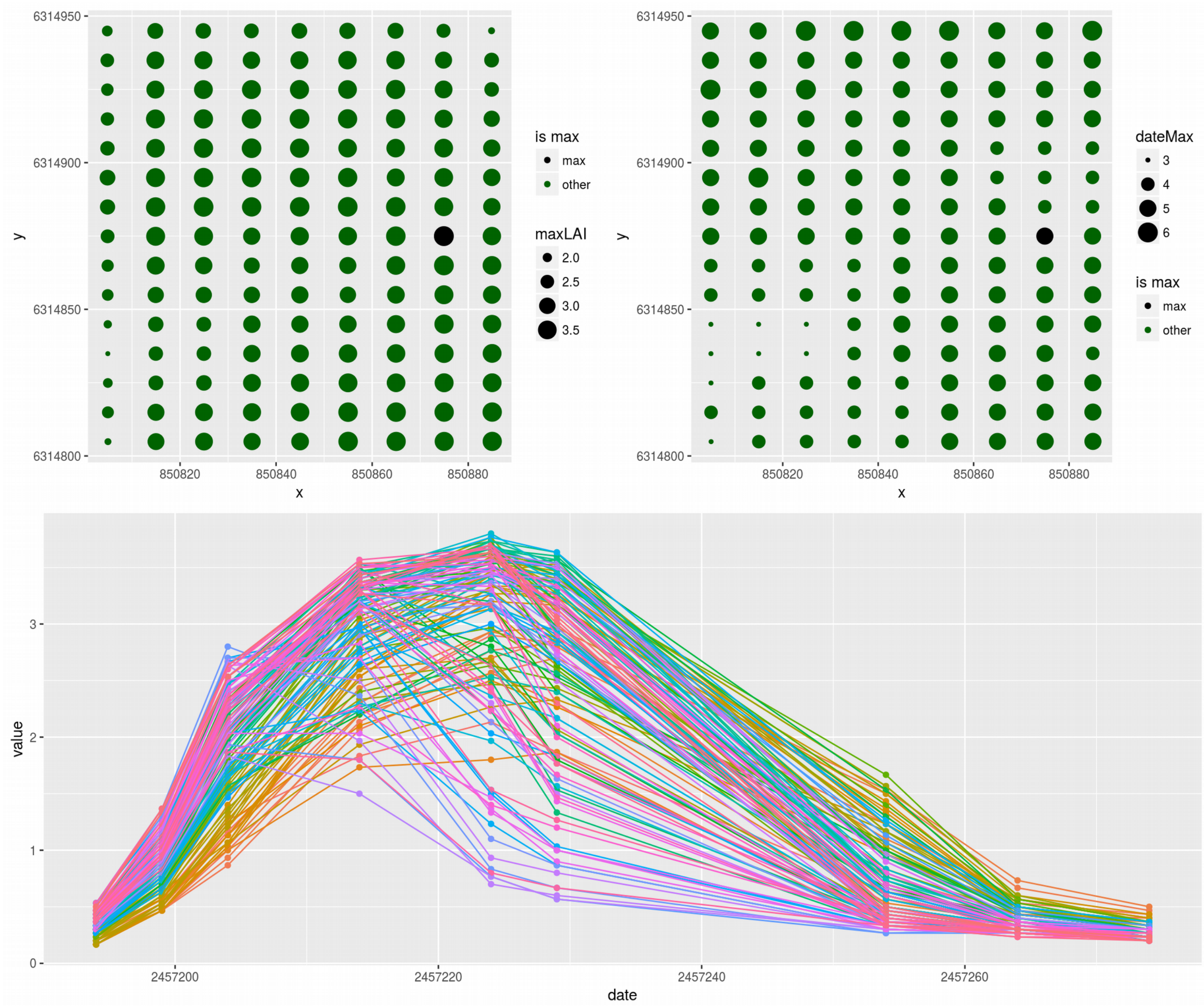
- Focus on Available Water Content (AWC): maximum quantity of water available for plant growth
- Estimations:
  - using laboratory measurements, pedotranfer functions (soil scientists)
  - in-situ monitoring of plant development, or inverse modeling of crop models (ecophysiologists and agronomists)
- The need to benchmark and compare these methods.

Data on one plot (RUEdesSOLS)



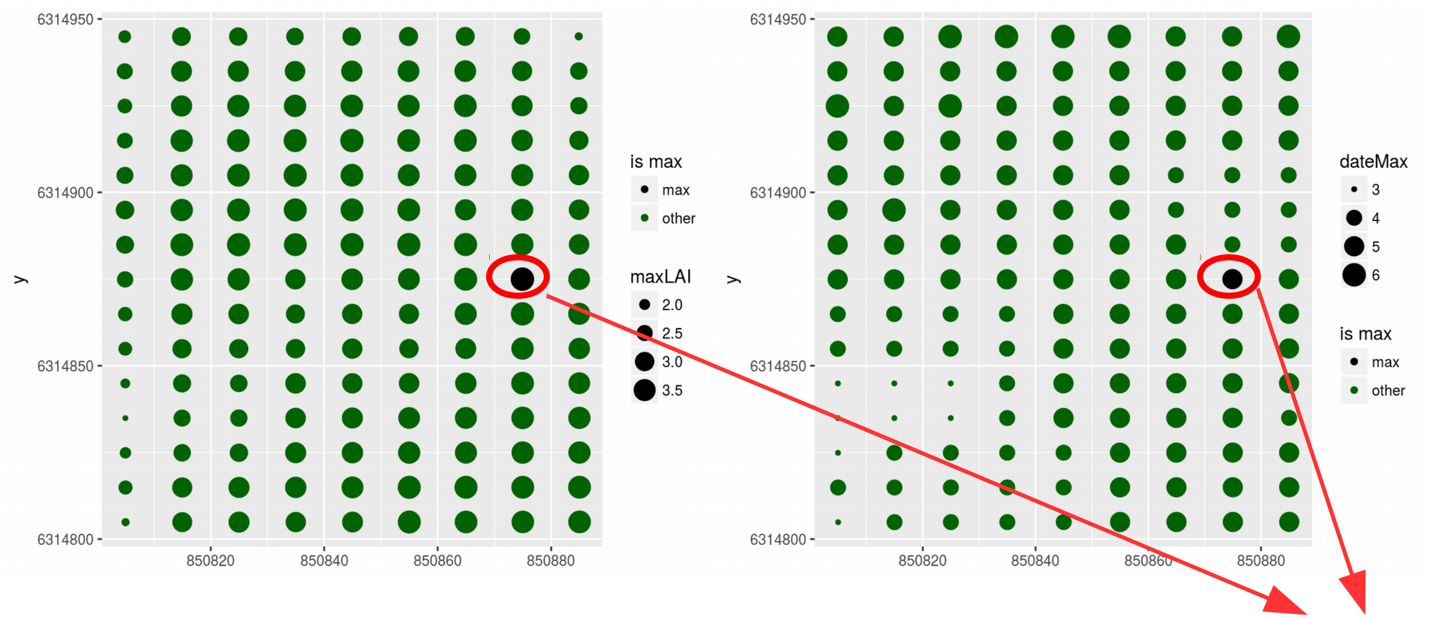
- Plot in Avignon France,
- 1.8 ha.
- Known soil properties

Remote sensing data (RUEdesSOLS)



- Sunflower 2015
- LAI estimation from SPOT-5 images

Inversion protocol assumption



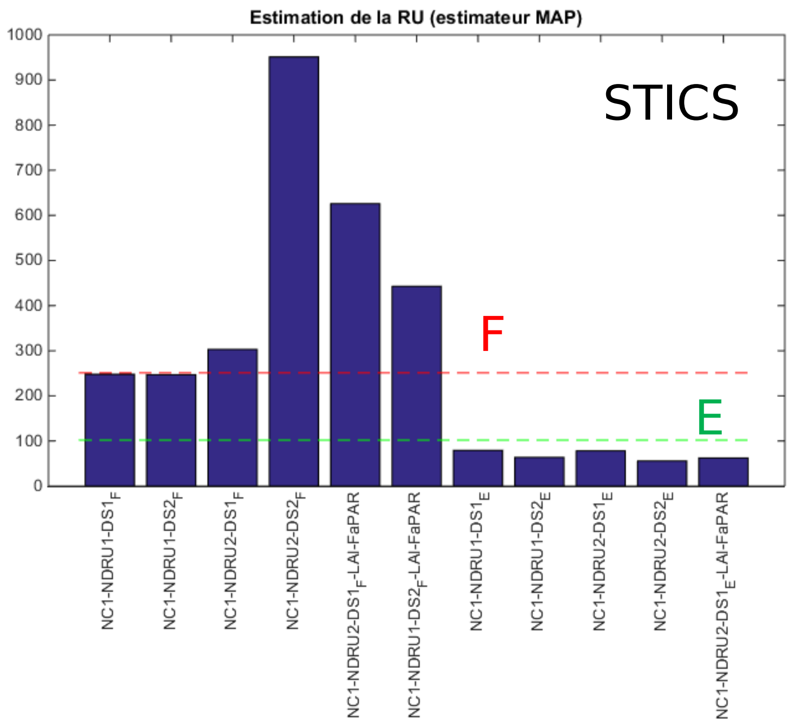
1) No water stress on the pixel where the highest LAI has been reached

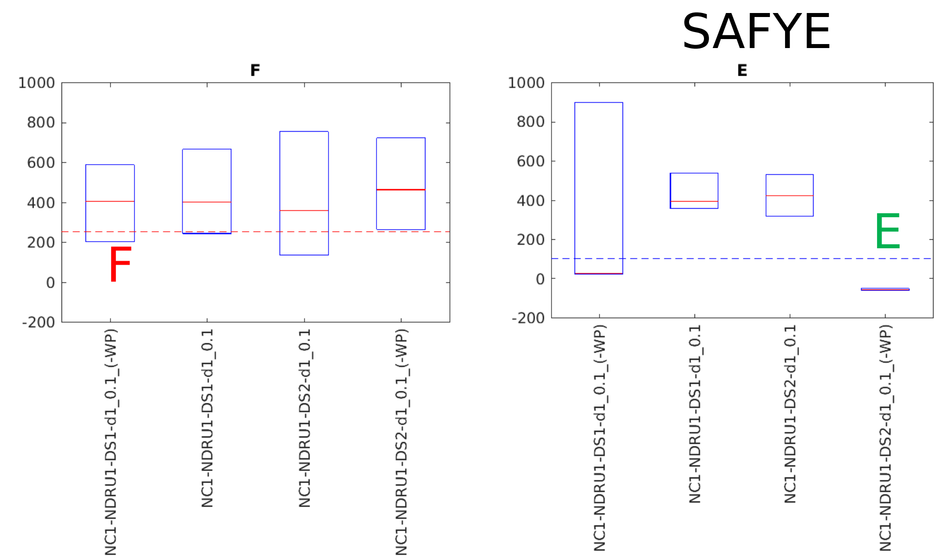
=> used for estimation of crop cultivar at the plot scale (phenology)

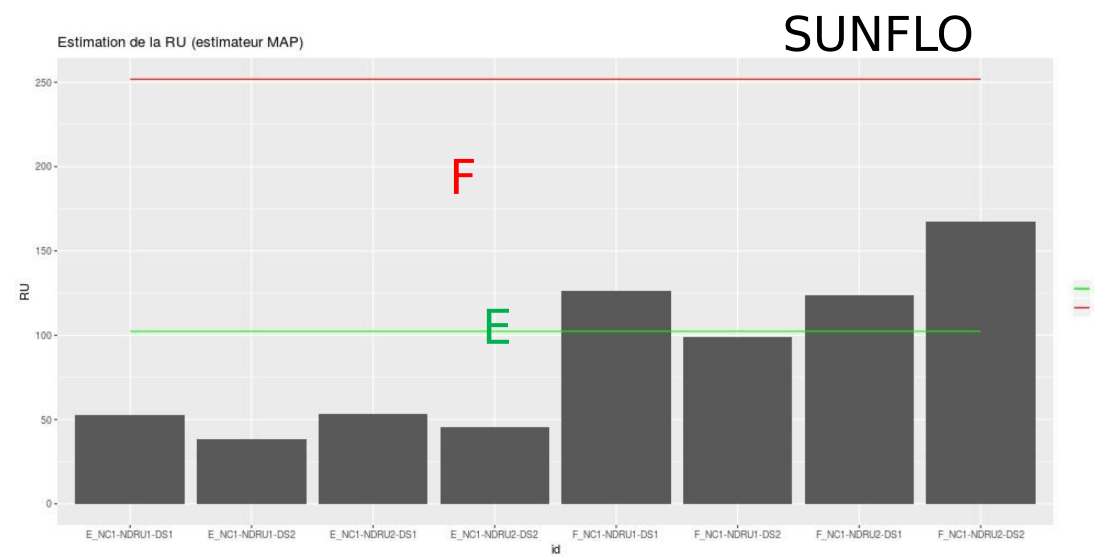
2) Intra variability of LAI is due to water stress only

=> estimation of AWC for other pixels

Inversion of AWC with 3 models







Few protocols (4) based on :

- soil discretization,
- AWC components to estimate

Inversion method

- Bayesian: MCMC (DREAM)

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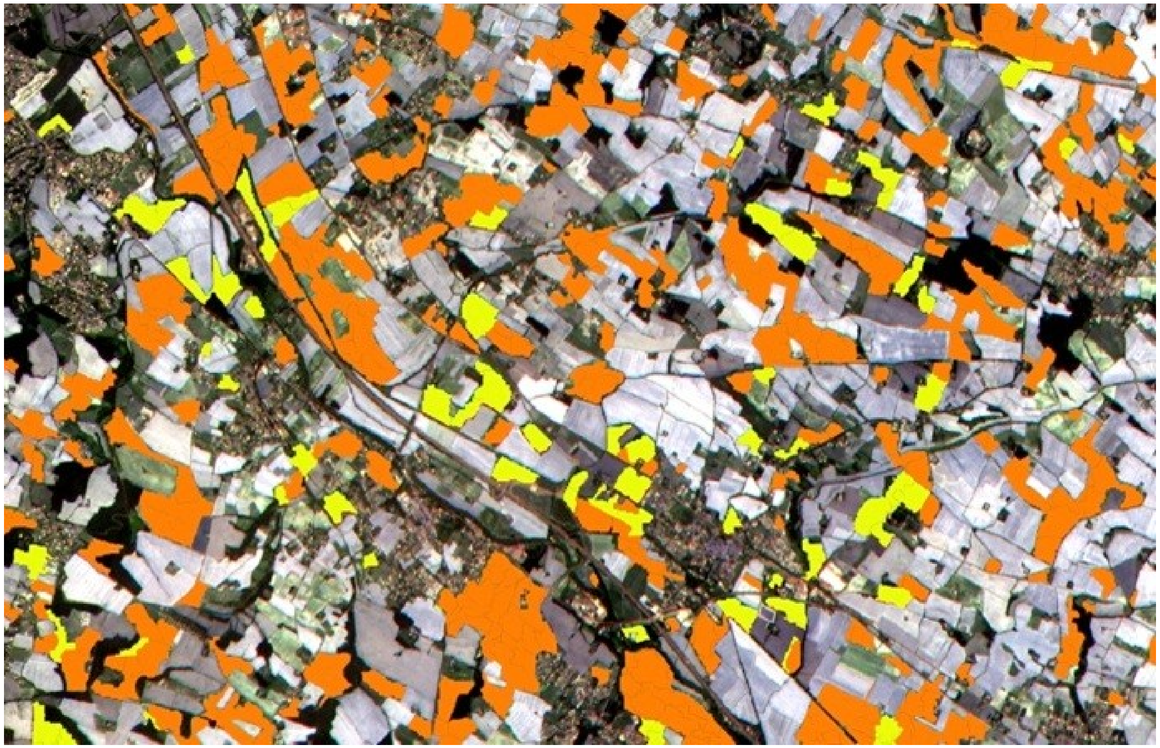
Casdar project

- Towards building a tool to forecast the yield of sunflower crop few weeks before harvesting
- At the plot scale or collection basin scale (1 or 2 silos)
- Modeling approaches based on crop model and remote sensing

Remote sensing data (Casdar)



land cover (Sentinel 2, July 6, 2015, Toulouse)

- 6 workable images in 2014 (Landsat 8, 30 metres resolution)
- 13 workable images in 2015 (SPOT5-Take5, 10 metres resolution)
- 5 workable images in 2016 (Sentinel 2a, 10 metre resolution)

=> NDVI for 221 sunflower crop-year -> LAI dynamics

Plus: survey and crop monitoring (management, cultivar, ...)

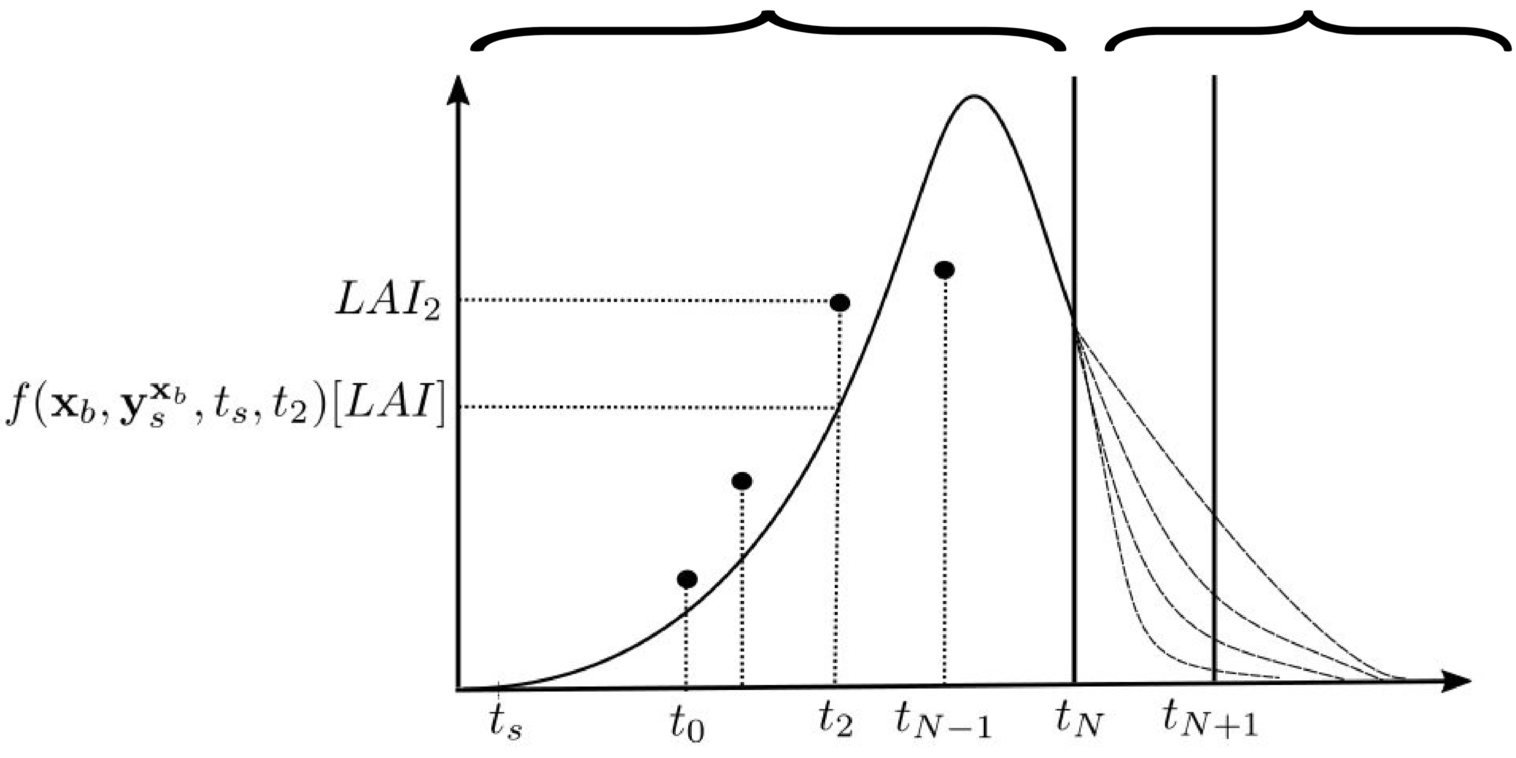
Approaches to build the tool

- The will to compare different approaches:
  - empirical models on remote sensing: require building statistical models for temporal variables (LAI, NDVI) and bootstrapping the model.
  - complex approaches such as data assimilation in crop models: require information on model inputs
- Forecast is performed independently for each plot (no spatial correlation)
- Few weeks before harvesting means August 10^{th}.
- In data assimilation, uncertainty on initial conditions are related to AWC (according to previous results)

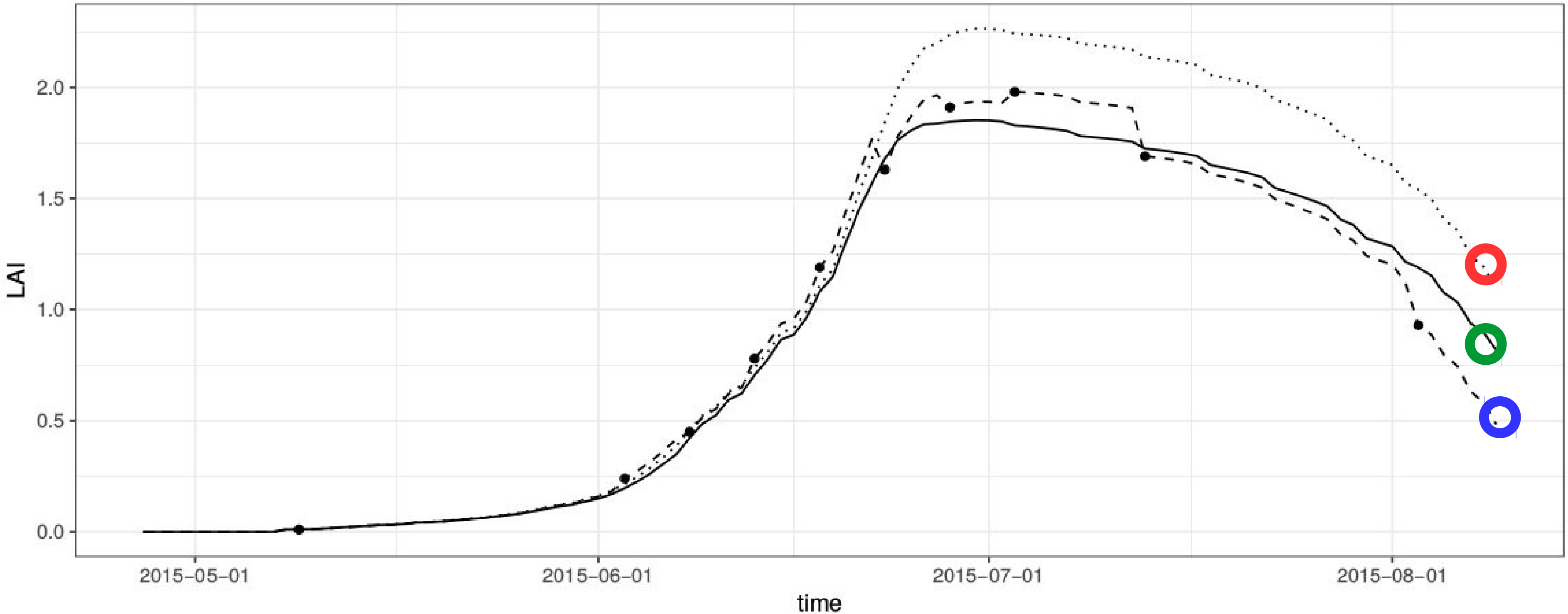
Defining/solving the forecast problem

Updating model state at tn:
- simulation
- forcing LAI
- re-estimation of AWC
- Ensemble Kalman Filter

Forecasting :
- oracle
- past climate



Simulating, forcing LAI and re-estimating AWC



Simulation without taking into account observations

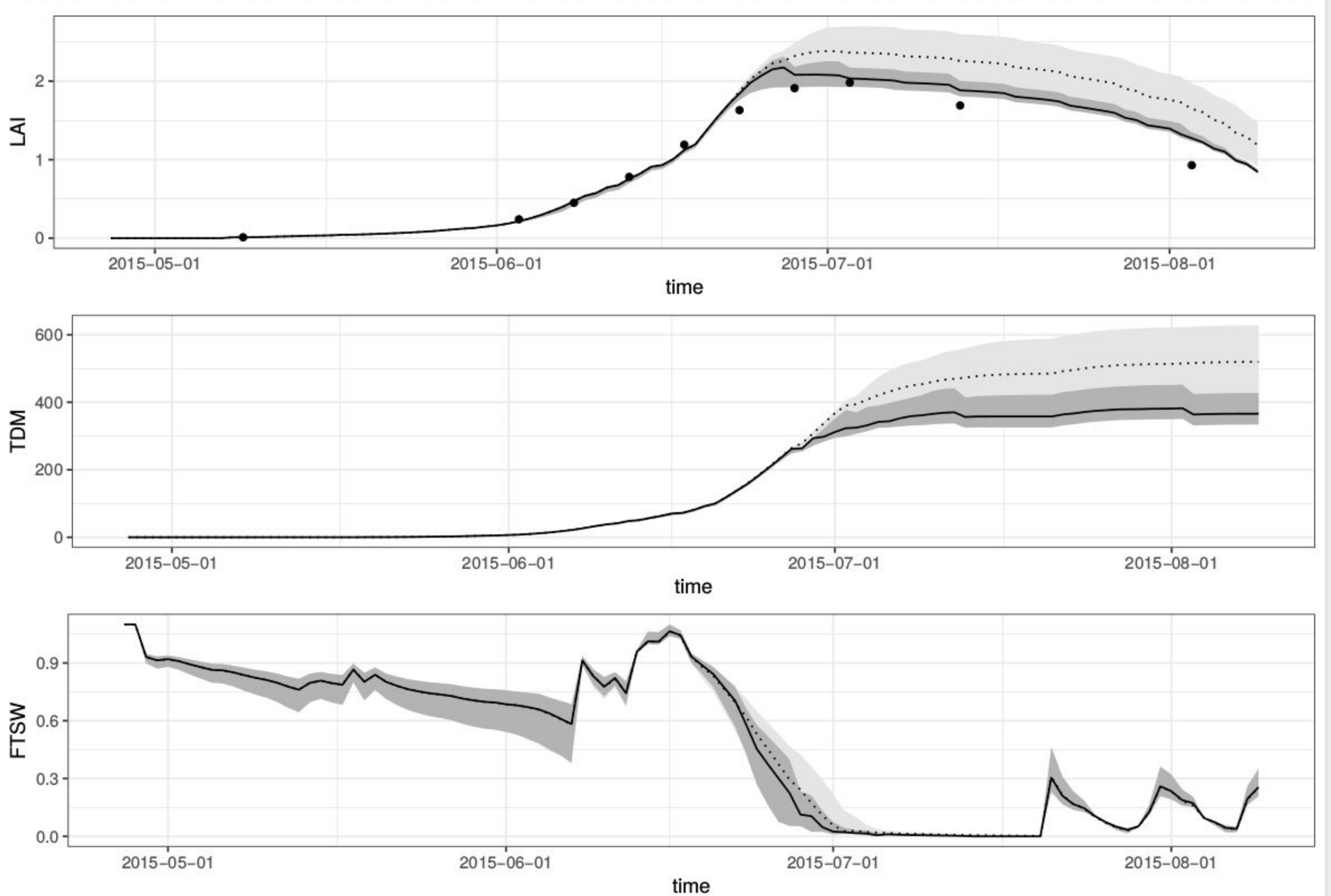
Forcing LAI at times of observation

Finding AWC components that minimize mean square error on LAI (using genetic algorithm)

Ensemble Kalman Filter

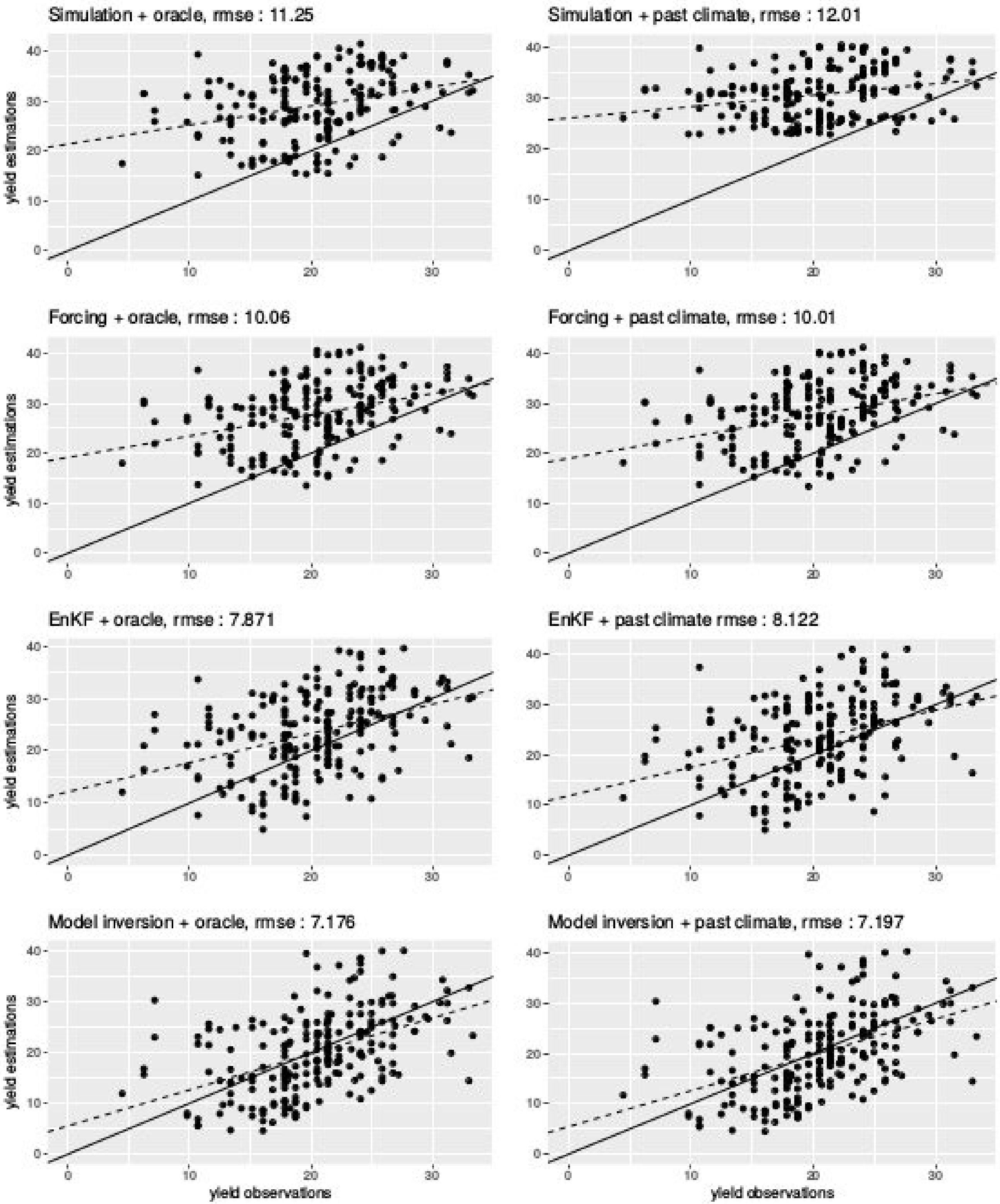
At each time of observation ti:

$$\mathbf{k} = \mathbf{B}\mathbf{h}^T(\mathbf{h}\mathbf{B}\mathbf{h}^T + \mathbf{R});$$
$$\forall m \in \{1, ..., M\}, \mathbf{y}_m \leftarrow \mathbf{y}_m + \mathbf{k}(LAI_i - \mathbf{h}\mathbf{y}_m)\ ;$$
$$\forall m \in \{1, ..., M\}, \mathbf{y}_m \leftarrow f(\mathbf{x}_m, \mathbf{y}_m, t_i, t_{i+1});$$



=> updating state variables using their covariance:

leaf are index (LAI), total dry matter (TDM), root depth (zRac), fraction of transpirable water (FTSW), cumulated transpiration between the flowering and maturity stages (TRPF) water content of the two soil layers (C1 and C2) total absorbed nitrogen (Nabs)



RMSE Results:

simulation (12) <
forcing LAI (10) <
EnKF (8) <
re-estimation of AWC (7)

RMSE improvement with the 'oracle' forecast : 0.3

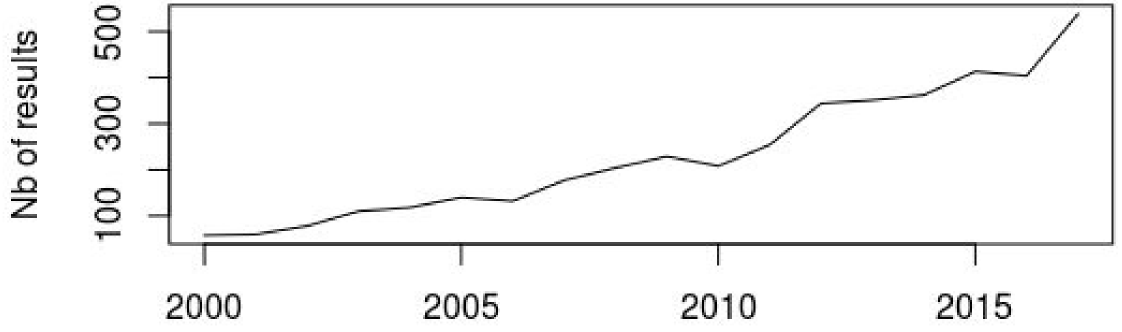
(Trepos et al. in progress)

Impact of yield-limiting factors

weeds	disease	cover irre-gularities	number of plots	% of good predictions			
				sim.	forcing	EnKF	inversion
-	-	-	221	7	23	32	30
yes	-	-	87	3	15	23	25
-	yes	-	109	7	23	31	*33*
-	-	yes	121	2	23	25	25
yes	yes	-	38	3	16	24	21
yes	-	yes	60	0	18	18	20
-	yes	yes	54	4	*26*	28	*31*
yes	yes	yes	23	0	*26*	22	17
no	no	no	33	15	27	**52**	33

Conclusion

- Overview of a process-based crop model
- Estimating AWC with remote sensing and crop models
  - An inversion protocol conducted with 3 models.
  - On going: the use of more integrated Bayesian approaches (prior, constraints, …) and take advantage of the posterior distribution.
- Forecasting yield by coupling remote sensing and crop model during the crop season :
  - Advantages of the use of remote sensing and advanced modeling techniques
  - Requirement in modeling (yield limiting factors)
  - On going here at GISS : at a larger scale (county, state) using MODIS products.
- Growing interest in coupling "crop models" AND "remote sensing" according Google Scholar (?)



Thank you !

- Casadebaig et al. 2016, "A model-based approach to assist variety evaluation in sunflower crop", European Journal of Agronomy, vol 81, 92 -- 105
- Casadebaig et al. 2011, "SUNFLO, a model to simulate genotype-specific performance of the sunflower crop in contrasting environments", Agricultural and Forest Meteorology, vol 151(2) 163 -- 178
- Trépos, R., Debaeke, P., Dejoux, J-F. , Champolivier, L., Al Bitar, A., Casadebaig, P. (in progress) "Assimilating remote sensing observations in a sunflower crop model under uncertainty on soil properties"